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EXPLODING PUSHER PERFORMANCE AT FIXED LASER POWER - A THEORETICAL MODEL

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ABSTRACT

A model for the physics of exploding pusher targets is presented which compares favorably with the predictions of the complex simulation code, LASNEX.

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Exploding pusher targets[1] have been the most common targets of early laser fusion experiments, and are even slated to be the first targets to be shot on the 20 TW SHIVA laser system at Lawrence Livermore Laboratory. They consist of a glass microballoon filled with DT gas. For SHIVA, typical dimensions are radius 200 μ, thickness 2 μ, and DT fill 5 mg/cc.

There are many reasons for their popularity. They are relatively easy to fabricate and diagnose, and require no special temporal laser pulse shaping other than the usual gaussian. As will be explained below, their physics requirements are also less stringent than the usual high compression, isentropic implosion targets that will ultimately lead to economical energy production.[2]

The exploding pusher target heats the DT ions to thermonuclear temperatures (a few keV) via a three-step process. An intense laser pulse rapidly heats the glass microballoon, and preferentially heats the electrons. Because of its density the electron-ion coupling in the glass is good and the glass ion temperature is also raised. The electron thermal wave rapidly proceeds through the glass and into the DT gas, heating the DT ions slightly (low DT density ⇒ low electron-ion coupling). The energy deposition occurs so quickly in the glass that the shell explodes. Roughly half its mass explodes outward, the remaining half inward.

The imploding half of the shell acts as a piston, driving a shock through the DT that principally heats the ions. The glass shell then continues to move inward, adiabatically compressing the post-shock region of DT, thus further heating the ions to thermonuclear temperatures. The DT thermal pressure builds up and eventually stops the inward moving glass. The fusion reactions occur until the DT is cooled by thermal conduction and by expansion.

Whereas the high-compression, isentropic implosion targets are sensitive to electron preheat and to Rayleigh Taylor instability, exploding pushers, by virtue of their rapid thermal wave early heating and by their non-ablative implosion dynamics, are not sensitive to the aforementioned problems.

In order to predict the neutron yield, Y, we note that

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$$Y \sim Mn\overline{\sigma v}\tau_c \tag{1}$$

where M is the DT mass, n its compressed number density, $\overline{\sigma v}$ is the product of velocity and fusion cross sections averaged over a Maxwellian distribution, and τ_c is the confinement time. Since $M \sim \rho_0 R^3$ where ρ_0 is the initial DT fill density and R the initial radius; since $n \sim \rho_0 \eta$ where η is the compression ratio $(R/R_{final})^3$; and since $\tau_c \sim R_F/C_s^0 \sim (R\eta^{-1/3})/\theta_i^{1/2}$ where θ_i is DT ion temperature at compression, Eq. (1) becomes

$$Y \sim \rho_0^2 R^4 \eta^{2/3} (\overline{\sigma v}/\theta_i^{1/2}) \tag{2}$$

Since $\overline{\sigma v}$ is a known function of θ_i, we must find expressions for η and θ_i, in terms of the initial parameters ρ_0, R, P(t) (the absorbed laser power) and ΔR the initial shell thickness.

The compression η is found by appealing to the fact that 1/2 of the glass mass eventually fills most of the original sphere. The average glass density, $\overline{\sigma v}$, at turn-around time (= maximum compression time) is then given by

$$\overline{\rho_g} = 4(\Delta R/R) \tag{3}$$

where a term of order $1/\eta \sim .01$ (due to the space taken up by the compressed DT) is ignored. Since the density profile of the glass is found to fall off as $1/r^2$, it follows that the central glass density (at the DT-glass interface) ρ_{gc}, equals $\overline{\rho_g}\eta/3(\eta^{1/3} - 1)$. Due to pressure equilibration and thermal conduction we can set ρ_{DT} roughly equal to ρ_{gc}. But $\rho_{DT} = \eta\rho_0$. Thus Eq. (3) leads to

$$\eta \approx (1 + 1.3\ \Delta R/R\rho_0)^3 \tag{4}$$

To find θ_i we recall the heating process is roughly a shock to temperature θ_0, followed by adiabatic compression, thus

$$\theta_i \sim \theta_0 \eta^{2/3} \tag{5}$$

Behind a strong shock the internal energy matches the kinetic energy and thus $\theta_0 \sim V_0^2$ where V_0 is the initial explosion velocity. But

$$V_0^2 \sim \int_{-\infty}^{t} P(t')dt'/R^2\Delta R \tag{6}$$

where $R^2\Delta R$ represents the mass of the glass shell. The integration is done until a time τ when the shell has moved in some 15% of its initial radius, because by then the shock has passed through 1/2 the DT mass.

We know that $r(t) = R - \int_{-\infty}^{t} v(t')dt'$ and so that t can be determined requires a normalization to a single LASNEX code result in order to find the coefficient in Eq. (6). Thus with a single LASNEX result we can scale to other radii, thicknesses and DT fills with this model. Comparisons of those predictions with LASNEX results are quite favorable. Table I shows such a comparison for a pellet of 1 μ thickness, variable radius, 5 mg/cc fill, 10 TW absorbed, 100 ps FWHM gaussian. The theory is normalized to LASNEX for the 150 μ radius ball.

Table I

R(μ)	LASNEX Y (10^{11} neutrons)	Theory Y	LASNEX θ_i(keV)	Theory θ_i	LASNEX ρ_F	Theory ρ_F
150	6.5	6.0	11.0	10.5	.10	.10
175	8.5	8.0	9.4	8.8	.08	.08
200	10.0	9.2	8.3	7.6	.07	.06

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